LABORATORY TESTS ON ROCKS (Lecture-III)

1. INTROUCTION

Design in rock is really special due to the following reasons

1. In rock structure applied loads are less significant than forces deriving from redistribution of initial stresses.
2. It needs as much judgment as measurement.
3. Geological section of site is important.
4. Closely related with/allied with geology and geological energy.

Therefore we need the following in Rock Mechanics

1. Meaningful tests
2. Calculations
3. Observations

Some terms related with rock mass are as described below.

Nature of rock mass: It is a discontinuous, anisotropic and non-homogeneous naturally occurring prestressed medium.

Discontinuity is due to the actions of tectonic forces.

The influence of joints, their configuration and the structure along them will have to be considered in the analysis and design.

Continuum approaches are not applicable in rock mass analysis.

Depending upon the ratio of mass considered to the spacing of joints, the rock mass is often treated as continuous for its overall behaviour.

'Striation' means a series of ridges, furrows or linear marks and is caused due to geological faults.

Slickenside: In geology, a **slickenside** is a sooth policed surface caused due to friction movement between rocks along the two sides of a fault. This surface is normally striated in the direction of movement.

Portal: The area near to the tunnel is called the portal of the tunnel. The tunnel never passes into the portal, but the strength of a portal affects the life and strength of the tunnel.

Surface investigation

- Determination of dip and strike of the rock beds through a Brunton compass
- Identification of geological structures and lithological characteristics and
- Study of drainage pattern

Subsurface investigation

- Bore hole drilling to get depth wise characteristics
- Resistivity survey to get information about rocks and fractures
- RQD, etc

Outcrop: The rocks through which tunnels are proposed to be excavated are called outcrop.

Tensile Strength of a rock is about 1/10 to 1/8 of its compressive strength.

Shear Strength: It is resistance to deformation of the rock due to shear stress.

Young's Modulus: Rocks generally fail at a small strain, typically around 0.2 to 0.4% under uniaxial compression. Most rocks behave brittle under uniaxial compression. However, a few soft rocks, mainly of sedimentary origin, behave ductile.

- Rocks, which have a high tensile strength and hardness without any fractures, are most suitable for tunneling.
- Granite, basalt, gabbro, dolerite and syenite are favorable rocks; although expenditure for excavation is too high.
- Rocks should be massive with least permeability.
- The older rocks are more massive and harder than younger rocks.
- Groundwater fluctuations: Less fluctuation are preferred as higher fluctuation weakens the rocks due to moisture content and ultimately damages the tunnel.

2. LABORATORY TESTS ON ROCKS

The strength, modulus and stress-strain response of rocks are influenced by mineralogical content, extent of pores and presence of pore fluid, more often water. Rock cores are subjected to various tests in the laboratory to determine their mineralogical composition, physical and engineering properties. Micrographic test are generally carried out for petrographic description of rocks to indicate the mineral content, grain size, texture fabric, degree of alteration/weathering, micro fracture and porosity. These tests are conducted by geologists in laboratory on thin sections of rock. The different laboratory tests on rocks are as described below.

2.1 Micrographic tests are done for petrographic descriptions of rocks e. g.

1. Mineral content
2. Grain size
3. Texture fabric
4. Degree of alteration/weathering
5. Micro fracture
6. Porosity

2.2 Physical properties

1. Dry, bulk and saturated densities
2. Water content, porosity/void ratio, degree of saturation and specific gravity/relative density.

2.3 Engineering Properties

1. Unconfined compressive strength to obtain compressive strength, modulus, Poisson's ratio including mode of failure.
2. Brazilian test to obtain tensile strength.
3. Shear tests to obtain strength envelope, strength parameters of chosen failure strength criteria, stress-strain response and variation of modulus and mode of failure/change in mode of failure with changing purpose.

4. Permeability test to determine the coefficient of permeability which represents the relative interconnection of pores

2.4 Other Tests

1. **Point load strength index test** to obtain compressive and tensile strength of regular or irregular rock samples.
2. **Slack durability test:** to ascertain the resistance of rock samples to disintegrate when subjected to specified cycles of wetting and drying.
3. **Sound velocity test** by elastic wave propagation of P-wave and S- wave to estimate dynamic elastic constants e g. modulus of elasticity, modulus of rigidity and poisons ratio. It helps to get the petrographic description i. e. evaluation of degree of fissuring.
4. **Swelling test** on regular size sample to get degree of swelling and swelling pressure under non swelling condition.
5. **Schmidt rebound hardness test** to obtain hardness and compressive strength.

3. Point Load Strength Index Test

The name of the apparatus is Broch and Franklin' apparatus. Rock is loaded between hardened steel cones causing failure from development of tension cracks parallel to the axis of loading.
Point load strength = $I_s = P/D^2$ for length of the sample ≥ 1.5 * diameter of drill core. Point load is found to fall by a factor of 2 to 3 as one proceeds from cores with diameter of 10 mm to 70 mm. therefore, diameter of the core has been standardized as s 50 mm size.

Correlation between UCS and I_s

$$q_u = 24\, I_{s(50)} \qquad \text{……………………} (1)$$

Where UCS with l/d = 2 to 1, $I_{s(50)}$ is point load index for a core sample of 50 mm diameter.

This test has the following advantages:

1. It is quick and simple.
2. It can be done in field during drilling
3. It can be shown on the drilling log.

4. Slake Durability Test

Cylinder diameter is 140 mm and length is 100mm
20 revolutions/minute in water bath for 10 minutes are given to the sample. Gamble (1971) proposed second 10 minutes cycle after drying varies from 0 to 100%.

Group name	**% referred after 1st 10 min cycle on dry weight basis**	**% referred after 2nd 10 min cycle on dry weight basis**
Very high durability	>99	>98
High durability	98-99	95-98
Medium high durability	95-98	85-95
Medium durability	85-95	60-85
Low durability	60-85	30-60
Very low durability	<60	<30

The test is conducted on rock samples to ascertain their resistance to disintegration when subjected to two specified cycles of drying and wetting. The test is conducted as per the specification in a standard apparatus. Ten over-dried representative rock lumps, each of 40-60 g, i.e. 0.4 to 0.6 N mass with a total mass of 450-500 g, i.e. 4.5 to 5.0 N is placed in the 140 mm diameter cylindrical rum having 2.0 mm mesh. The drum is supported on a trough containing tap water at 20^0 C, such that the water level is 20 mm below the supporting axis of the drum. The drum is rotated by a motor at a speed of 20 rpm for 10 min. After 200 revolutions, the lumps are again subjected to second cycle of revolutions, oven-dried and weighed. The slake durability index (second cycle) is calculated as the percentage of final to the initial dry mass of rock umps as

$$I_{d2} = \frac{W_3}{W_1} \times 100\ (\%) \qquad (2)$$

Where, I_{d2} = slake durability index, W_1 = the initial dry mass and W_3 = the final dry mass.
Usually while weighing, the weight of the drum with rock samples inside, is taken in both the cycles. The slake durability index is reported to the nearest 0.1%. If the I_{d2} is between 0 and 10%, the slake durability index (I_{d1}) based on the first cycle of drying and wetting is estimated as:

$$I_{d1}= \frac{W_2}{W_1} \times 100\ (\%) \qquad (3)$$

Where, W_2 is the dry mass after the first cycle.
Rocks showing low slake durability index (often argillaceous) are subjected to Atterberg's limits and grain size analysis as per soils classification. Based on I_{d2}, rocks are classified (ISRM 1981) as per the table given below. Slake durability test set-up is shown in figure given below.

Table: Classification of Rocks Based on Slake Durability Index

I_{d2} (%)	**Classification**
0 – 30	Very low
30 – 60	Low
60 – 85	Medium
85 – 95	Medium high
95 - 98	High
98 - 100	Very high

5. Tensile Strength Test

- This test is also called Splitting Test or Brazilian Test or Diametrical Compression Test.
- It is an ISRM recommended method for measuring tensile strength of rocks.
- It is amongst the most common tests used for geotechnical investigation of rocks.
- Sample is disc shaped and the diameter is not greater than core size i.e. 54mm or atleast 10 times the average grain size, i.e. t/d = 0.5 to 0.6
- Load is continuously increased at a constant rate until failure occurs within a few minutes.
- Rate of loading = 10 kN/min to 50 kN/min and it depends upon the material to be tested.

$$\sigma_t = \frac{2P}{\prod DL} \qquad \text{............(4)}$$

Where, P = applied load, D= diameter=2R, L= Thickness of sample

- The loaded width at the ends should be less than 1/10 of the diameter of the sample.
- Fracture initiates from the center and progresses towards the loaded ends.
- If the fracture starts from the ends, the test is discarded.
- Tensile strength decreases with increase in volume or length of the sample due to micro fractures.

The test is also conducted for other types of rock samples.

For cylindrical sample (Reichmerth, 1962)

$$\sigma_t = \frac{0.96P}{D^2} \qquad \ldots\ldots\ldots\ldots(5)$$

The length of sample >diameter of the sample

For diametric compression of sphere

$$\sigma_t = \frac{0.9P}{D^2} \qquad \ldots\ldots\ldots\ldots(6)$$

For compression of cuboidal or plate

$$\sigma_t = \frac{1.96P}{\prod Lt} \qquad \ldots\ldots\ldots\ldots(7)$$

Where L= length of sample and t = thickness of sample

Point Load Test (ISRM, 1985): The tensile strength of an irregular sample is given by the following equation with usual notations.

$$\sigma_t = 1.25 I_{550} \qquad \ldots\ldots\ldots\ldots(8)$$

6. Shear Strength Test

Stress and Strain

How can we know it the rock will flow, yield, crown, crack, and buckle or otherwise give way to service. We should know how rocks usually fail i.e. whether in bending, shearing, crushing or otherwise. Normal strains in tri-axial compression specimen can be measured with surface-bonded electric resistance strain gages.

i.e $\epsilon_{axial} = \frac{\Delta l}{l}$, $\in_{lateral} = \frac{\Delta d}{d}$ and $\in_{lateral} = -\nu\epsilon_{axial}$

For linearly elastic and isotropic rock ν = 0 to 0.50. Normally, ν assumed as 0.25 for rocks

$$\frac{\Delta v}{v} = \in_{axial} + 2 \in_{lateral}$$

$$= \in_{axial} - 2\nu \in_{axial}$$

$$= (1 - 2\nu) \in_{axial}$$

A testing machine is a reaction frame in which a screw or a hydraulic cylinder is operated to load a specimen. Donaldson (1974) has reported decrease in compressibility and increase in modulus of elasticity with increase in resistivity for monzonite.

6.1 Direct Shear Test: This test is conducted on four types of samples as given below.

1. Test on intact specimen
2. Test along a joint
3. Test on gouge material
4. Test on irregular lumps of rock

Shear strength will be maximum for an intact rock and minimum in the case of a horizontal smooth plane. For gouge material: with slickensides, the rock must have reached the residual stage, i. e. c_r' ≈ 0 and $\emptyset_r$' > 0.

6.2 Tri axial Shear Test

At least three samples are tested under different confining pressures to get the shear strength parameters.

Axial stress = $\sigma_1' = \frac{P}{A_o}$ with usual notations

The stress-strain curves is usually plotted with deviatoric stress ($\sigma_1' - \sigma_3'$) and axial strain ($\in_1$)

The shear strength between two planes can be measured by the following equation:

$$\tau = C + \sigma_n \tan\emptyset \qquad (9)$$

Where

τ = shear strength between two planes,
c =cohesion,
σ_n = normal stress acting on two planes and
$\emptyset$ = friction angle.

For conducting this test, the rock surface is prepared by careful manual chiseling. The rock/concrete blocks of 70 cm * 70 cm * 35 cm are prepared. The base of the rock block should coincide with the plane of shear. In the case of concrete to rock interface, the concrete mix used for the preparation of blocks is 1:2:4 (cement: coarse aggregate: fine aggregates). The concrete blocks are allowed to cure for 28 days.

Shear and normal stresses are computed as follows:

Shear stress = $\frac{P_s}{A} = \frac{P_{sa}\cos\alpha}{A}$ ……………………(10)

Normal stress = $\frac{P_n}{A} = \frac{P_{na} + P_{sa}\sin\alpha}{A}$ ……………………(11)

Where,

P_s = total shear force, in kg
P_n = total normal force, in kg
A = area of shear surface overlap corrected to account for shear and lateral displacements, in cm^2
α = inclination of the applied shear force to the shear plane, in degrees
P_{sa} = applied shear force, in kg
P_{na} = applied normal force, in kg.

The applied normal stress is reduced after each increase in shear stress by an amount $P_{sa}\sin\alpha$ in order to maintain the normal stress approximately constant during in-situ shear test.

Note: Barton and Choubey (1976) have proposed the following non-linear correlation for shear strength of joints.

$$\tau = \sigma \tan\{\text{JRC} \log_{10} (\frac{\text{JCS}}{\sigma}) + \emptyset_r\} \quad (12)$$

Where,

τ = shear strength of joint.
σ = normal stress across the joint
$\emptyset_r$ = residual angle of friction along the joint.
JRC = joint roughness coefficient and
JCS = joint wall compressive strength.

The joint roughness coefficients are suggested for ten types of roughness profiles of joints. The joint wall compressive strength may be equal to uniaxial compressive strength of rock material for unweathered joints, otherwise it should be estimated indirectly from Schmidt hammer index test. However, there is need for considering size effect on shear strength of joints.

6.3 Punching Shear Test

The punching shear test is a simple method to determine the punching shear strength of rocks. As per Gokhale (2000), for punching shear strength (τ_p) with electrical resistivity for igneous, sedimentary and metamorphic rocks found that there is linear increase in τ_p with respect to resistivity, ρ (ohm-m) on a log-log scale. The equation is valid for positive value of τ_p only.

$$\text{i.e. } \tau_p = 19.55\ log_{10}\rho - 68.9$$

$$\tau = \sigma_n' \tan(\emptyset_p \pm \text{i})$$

Where $\emptyset_p$ = friction angle on the horizontal plane and i = is the dilation angle

At failure "i" is the slope of the plot between ΔhandΔd. +ve sign is used when the block moves up and –ve sign is used when the block moves down.

The shear strength will be maximum for an intact rock and minimum in the case of horizontal smooth plane.

Direct Shear Test on group material: if the thickness is more than 20 mm its undisturbed sample can be tested in Direct shear test. Drained direct shear test on such materials will result in

$c_r' = 0$ and $\emptyset_r' > 0$ …………………… (13)

Where c_r' = cohesion intercept and$\emptyset_r'$= friction angle at residual state

Direct shear test on irregular lumps of rocks can also be conducted by embedding the irregular lump of rock in a matrix having shear strength higher than the rock sample as shown in the Figure.

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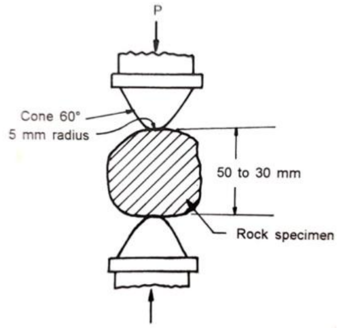


Figure 1 Point load test arrangement

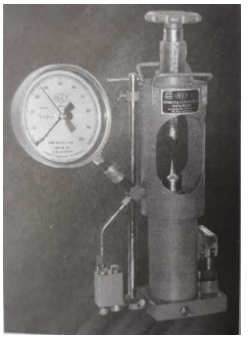


Figure 2 Point load tester

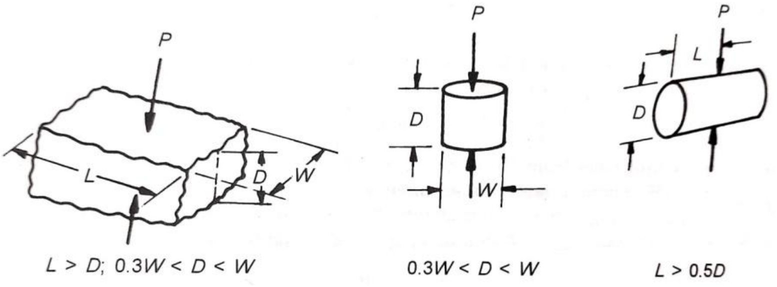


Figure 3 Point load test requirements on flat and regular specimens (ISRM 1985)

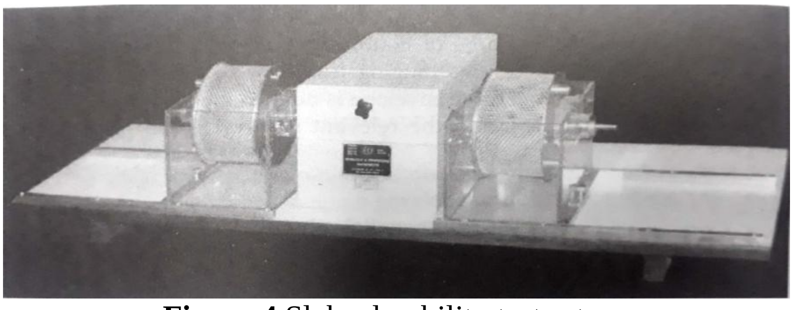


Figure 4 Slake durability test set-up

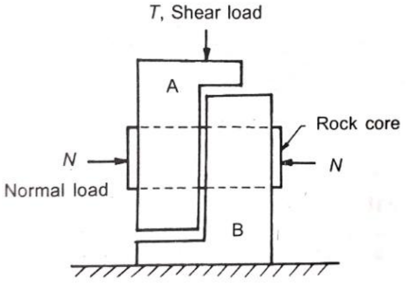


Figure 5

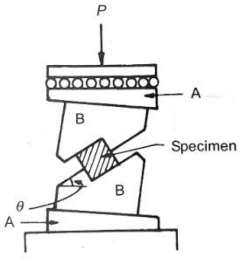


Figure 6

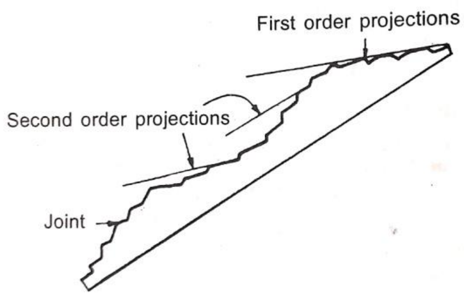


Figure 7

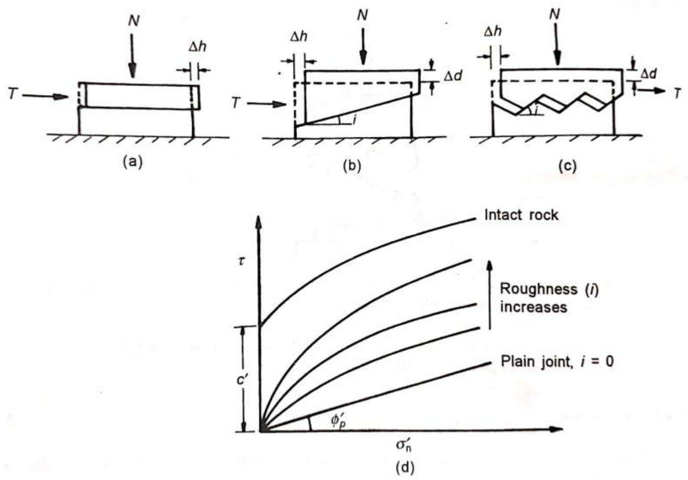


Figure 8

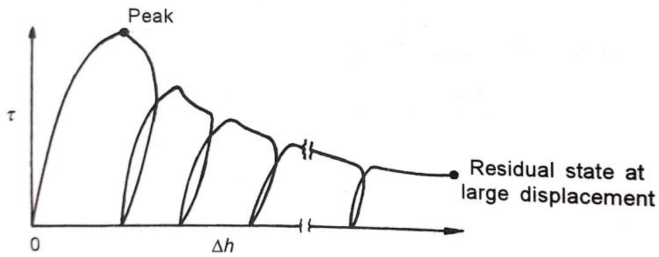


Figure 9

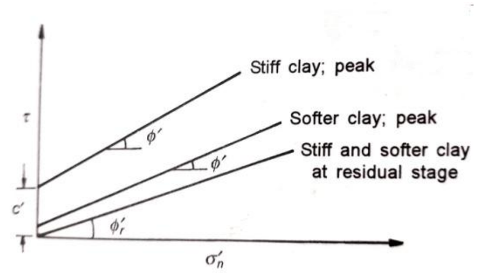


Figure 10

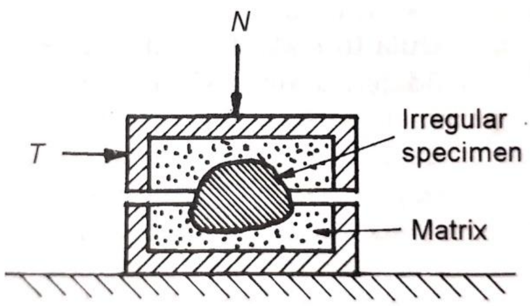
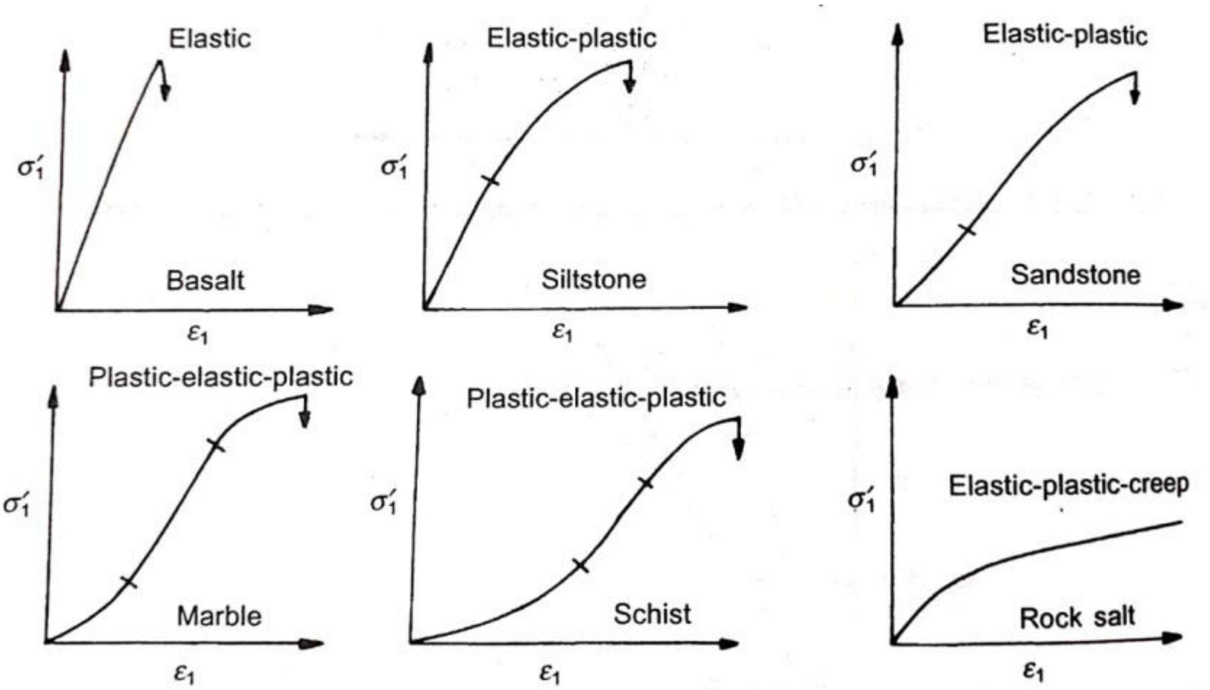
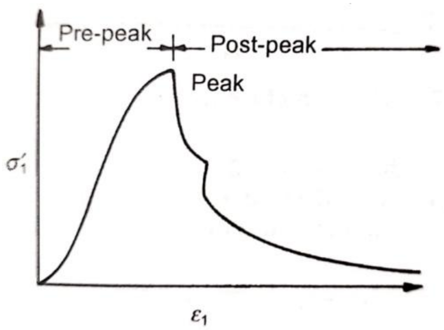


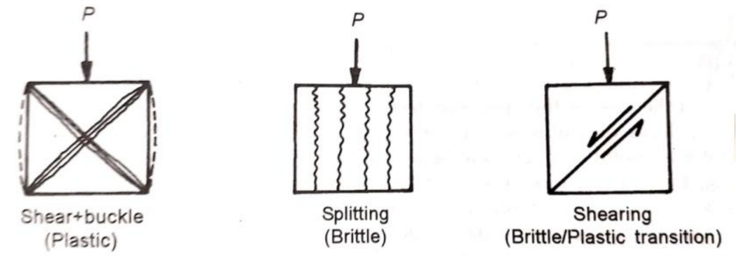
Figure 11



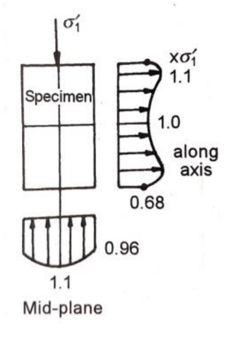
Elastic
Basalt
Elastic-plastic
Siltstone
Elastic-plastic
Sandstone
Plastic-elastic-plastic
Marble
Plastic-elastic-plastic
Schist
Elastic-plastic-creep
Rock salt
σ_1'
ε_1



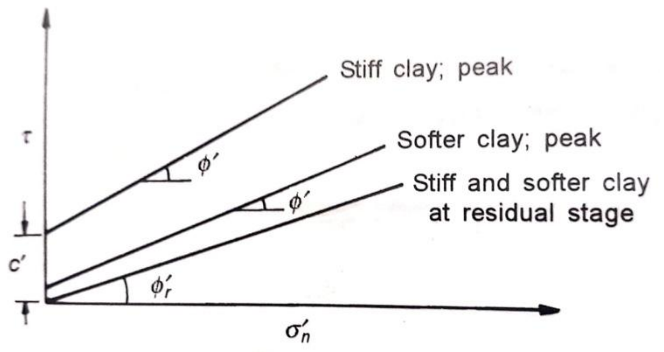
Pre-peak
Post-peak
Peak
σ_1'
ε_1

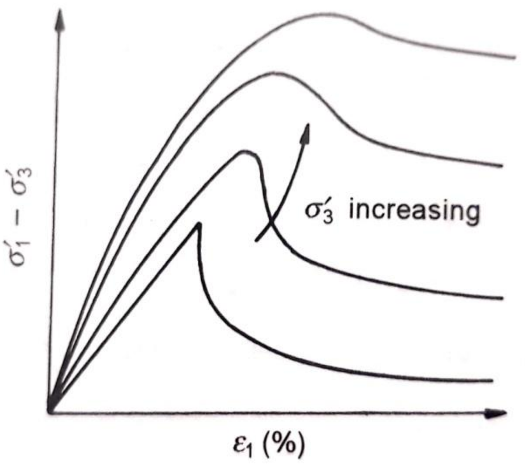


P
Shear+buckle
(Plastic)
Splitting
(Brittle)
Shearing
(Brittle/Plastic transition)



σ_1'
Specimen
$x\sigma_1'$
1.1
1.0
along
axis
0.68
0.96
1.1
Mid-plane


Stiff clay; peak
Softer clay; peak
Stiff and softer clay
at residual stage
τ
c'
ϕ'
ϕ'
ϕ'_r
σ'_n


$\sigma'_1 - \sigma'_3$
σ'_3 increasing
ε_1 (%)